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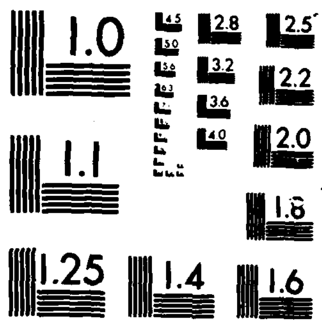

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RSRE MEMORANDUM No. 3891

ROYAL SIGNALS & RADAR ESTABLISHMENT

ROUTING OF HIGH DATA RATE SIGNALS USING DEGENERATE FOUR WAVE MIXING IN BSO

Authors: C L West and M G Hazell

PROCUREMENT EXECUTIVE,
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MEMORANDUM No. 3891

UNLIMITED

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Title: ROUTING OF HIGH DATA RATE SIGNALS USING DEGENERATE FOUR WAVE MIXING IN BSO

Authors: C L West and M S Hazell

Date: 1985

SUMMARY

Non-linear optical phase conjugation can be directly applied to real time spatial and/or temporal information processing of electromagnetic waves. In photorefractive materials the process may be described in terms of dynamic holography. The speed at which grating formation takes place is limited by the physical properties of the crystal and the intensities of the optical beams used to write the grating. The speed at which diffraction may occur from this grating does not, however, suffer such limitations and in this memorandum we demonstrate the use of degenerate four wave mixing in BSO to direct the flow of data whose information bandwidth exceeds 1MHz. (NETHERLANDS)

UNLIMITED

ROUTING OF HIGH DATA RATE SIGNALS USING DEGENERATE FOUR WAVE MIXING IN BSO

C L West and M S Hazell

1: INTRODUCTION.

Non-linear optical techniques have received increasing attention during the past few years. In particular the use of degenerate four wave mixing (DFWM) for the temporal and spatial processing of optically encoded information has been shown to provide a very powerful and versatile technique (1-5). In a DFWM experiment three optical beams incident on a medium interact non-linearly to generate an output field whose amplitude is proportional to the complex conjugate of one of the input fields. For the photorefractive material Bismuth Silicon Oxide ($Bi_{12}SiO_{20}$,BSO) the process can be described in terms of dynamic holography where two of the beams produce an interference pattern which is "written" into the crystal and off which the third beam is diffracted. To satisfy phase matching conditions in the interaction this read beam must be counterpropagating with respect to one of the write beams. From this comparison it can be inferred that the "write time" of the dynamic grating depends on the material constants and on the intensities of the two "write" beams; whereas the "read time" should have no such limitations, probably being ultimately limited only by the optical transit time through the grating.

Giuliano (2) has described the possible use of DFWM for covert communications where information, originally temporally modulating a pump beam, may be conveyed discretely to one or more receiver stations which have accessed the four wave mixing medium in the transmitting station with a suitable probe beam. Since the optical beams are many wavelengths in diameter the effective antenna gain is high reducing the required power transmission from the station and reducing sidelobe transmission making eavesdropping extremely difficult. In addition the phase conjugate nature of the returning beam will compensate for atmosphere abberations (1). In this memorandum we demonstrate experimentally for the first time the use of such a scheme to transmit data at MHz rates and discuss some of its limitations.

2: EXPERIMENTAL DETAILS AND RESULTS

The experimental arrangement is shown in figure 1. Two equal intensity write beams are derived from an Argon ion laser system and interfere in the BSO crystal. These beams are modulated by mechanical choppers C1 and C2 at rates up to 2kHz. The third beam is derived from the same source, and enters the crystal in a counterpropagating direction with respect to beam 1. This beam is modulated by a Coherent 304A Acousto-optic modulator which can operate from DC to 3.5MHz. The conjugate beam is collected by a beam splitter (BS3) in the second incident beam and focussed onto a fast detector. In order that the first and second beams can interfere to create a stationary grating it is necessary to configure the path difference between the optical source and the interaction region to be within the coherence length of the laser but no such limitation exists for the third beam.

Figure 2 shows experimental results for low frequency modulation (~kHz) of the read and write beams in the DFWM experiment. In figure 2a a write beam is modulated while in figure 2b the read beam is modulated. In both experiments the intensities of beams 1,2 and 3 were 17,28 and 80 mW respectively. It is clear that the two results are very different. In

dynamic holography the strength of the modulation index of the grating is given by (1)

$$m = \frac{2*(I(1)*I(2))^{1/2}}{I(1)+I(2)+I(3)}$$

and the diffracted signal is proportional to this modulation index multiplied by the read beam intensity I(3). Obviously if either of the write beams (1 or 2) are "off" then m=0 and there is no diffracted signal. If, however, both of the write beams are present the strength of the grating will depend on the presence or otherwise of the read beam. With the above values for the relative intensities of the beams we find m(on)= 0.35 while m(off)= 0.97 where off and on refer to the state of the read beam. This gives a ratio m(off)/m(on)=2.78. We are now in a position to interpret the data of figure 2. In figure 2b where the read beam is modulated we see that when the beam is off there can be no detected signal. When the beam is initially switched on the grating that will be sampled is the m(off) grating and has a high efficiency. As the new conditions take effect the signal decays to the steady state m(on) grating condition. When the beam is switched off the signal once more returns to the zero position. The leading and trailing edge of the signals have a time constant characteristic of the detector and chopper combination. It can also be noted that the m(off)/m(on) ratio is quantitatively in agreement with expectation. In figure 2a the signal is modulating one of the write beams. The signal rises and decays exponentially between a steady state write beam on and off condition. The high level is determined by the grating modulation index m(on) above while the lower level represents some average illumination in the formation of the grating.

In figure 3 the write beams are continually irradiating the sample. The read beam consists of a pair of 50us pulses separated by a time interval t with a repeat period of 1ms. The figure shows the results for three time intervals t=100,200 and 300us. All of the responses to the initial pulse of the pair have similar characteristics. In these cases the "off" state grating has had time to build up and stabilise. The second pulse, however, in two of the cases shown occurs so soon after the partial erasure of the "off" state condition that the crystal has not had sufficient time to recover and the signal shows a lower initial efficiency. Of course, all signals will show the tendency to decay to the final "on" condition. This figure highlights a potential problem of high data bit transmission. A single bit of data in isolation would have the high efficiency of diffraction of the "off" state, while a steady stream of data bits would have a diffraction efficiency more characteristic of the "on" state. This will have implications when setting thresholds and bit error rates for such a system.

Figure 4 shows the result of a high frequency modulation (~MHz) of the read beam. A 500ns pulse is repeated with alternating delays of 1 and 1.5us simulating a repeated fixed code digital data stream 10100. In the figure we show the raw experimental data, a thresholded version and the input data stream for comparison. The data is reproduced faithfully by the conjugate signal and is only limited in our experiment by the external time constants of the modulator and detector. A final systems limitation to such a system would be the time of flight of the coded signal through the non-linear medium. For a 10mm long sample this infers an upper bandwidth of approximately 10GHz.

3: CONCLUSION

In this memorandum we have demonstrated the transmission of 500ns pulses in a direction counter to that of a probe beam. The transmission rate is currently limited by the detector and modulator that we have used. We have commented on the possibility of using this technique for covert communications (1,2) where a remote station is accessed by a probe beam and where the data transmission is in a conjugate form to this beam. In practice this infers that the probe beam and the non-information carrying pump beam (figure 5) need to be temporally coherent and this would be difficult to acheive over large distances unless the local oscillator in the pump is derived from the probe. The other alternative involves the use of faster DFWM media where the point to point interaction is nearer to a true chi-3 susceptibility. In this case the upper frequency of operation would depend on the material characteristics. The technique descibed in the memorandum may, however be applied directly if one uses it for short range data routing where the same information may be required at various destinations and where crosstalk may be a problem. Such an application may be found for example in high speed data links for computers or even chip to chip interconnection. In addition, the technique applies equally well to the Fourier Plane Correlator (1,3,6) which uses DFWM for pattern recognition. In these systems a convolution or correlation is performed between two 2-d image planes. These image planes may be placed in the read or write beams, and when an image is in the read beam it may be refreshed at a rate that is determined only by the upper frequency limit of the system as described above. In such a correlator many test images could be compared to a scene if the test images are imposed on this read beam; the input scene, however, can only be refreshed at the slower material limited rate. As the correlator is invariant to position but not to changes in scale or rotation it would appear that the system would obviously benefit from this potential speed differential to test for many orientations and magnifications of a given test image resulting in a higher probability for target identification.

Future work would be aimed at overcoming the limitations of the technique with respect to coherence between the writing beams and demonstrating the technique in a more realistic systems application. In addition the functional dependance of the various time constants in the responses to system operating conditions (temperature,beam intensities) would be investigated.

4: ACKNOWLEDGEMENTS

The authors would like to acknowledge useful discussions with M F Lewis and A M Scott (RSRE), L C Laycock and C R Petts (GEC-HRC) and T Hall and M Fiddy (Kings College, London).

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6: FIGURE CAPTIONS

Figure 1: Experimental arrangement used to investigate the properties of the degenerate four wave mixing configuration using photorefractive BSO. The beam nomenclature for identification is defined by the choppers/ modulators C1 through C3. The conjugate signal is deflected by beam splitter BS3 and directed onto the detector by lens L7. All laser light in the experiment had a wavelength 514.5 nm. The beam intensities I1, I2 and I3 were 17,28 and 80 mW respectively.

Figure 2: (a) Low frequency modulation of one of the write beams, (1) or (2) in figure 1. (b) Low frequency modulation of the read beam (3). See text for explanation.

Figure 3: In this experiment the write beams are not modulated but are continually irradiating the sample. The read beam consists of two 50 us pulses separated by a time interval t with a repeat period of lms. The three right had responses corespond to delays of 100,200 and 300 us between the pulses and demostrates the recovery time of the system to a pulse.

Figure 4: High frequency modulation of the read beam. The read beam is modulated with a repeated 10100 coded waveform (INPUT). The conjugate signal (analogue waveform) follows the input data stream very closely even though the modulation rate is close to the upper limit of the modulator and the detector. A thresholded version of the conjugate signal data is also displayed in this figure. Note the input waveform is the electrical input waveform supplied to the acousto-optic modulator and not the input optical modulation.

Figure 5: Covert communication using Degenerate Four Wave Mixing. A continuous wave probe and pump beam interact with a temporally encoded pump beam to produce an encoded beam which propagates in the direction conjugate to the probe beam. The conjugate nature of the returning beam will compensate for atmospheric distortions. The high directionality of the probe and returning beam will reduce the possibility of eavesdropping.

PHASE CONJUGATION BY DEGENERATE FOUR WAVE MIXING

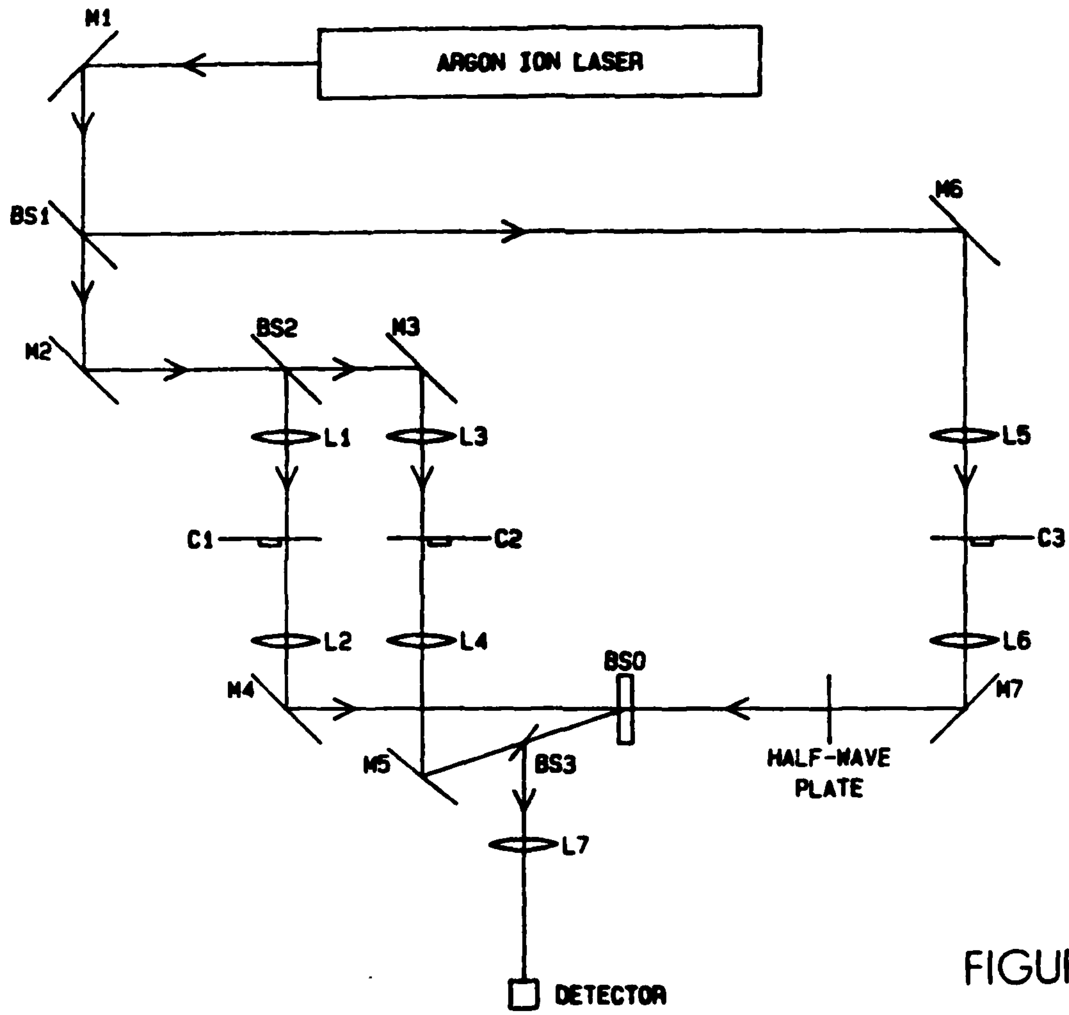


FIGURE 1

FIGURE 2a

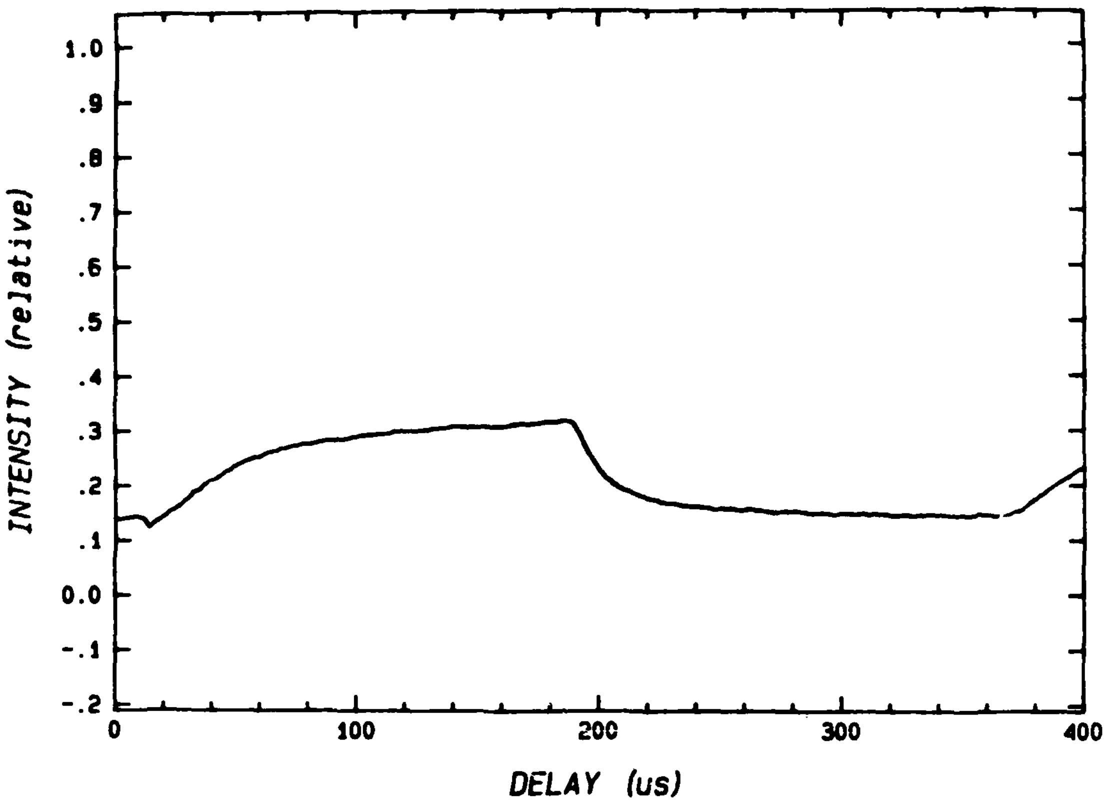


FIGURE 2b

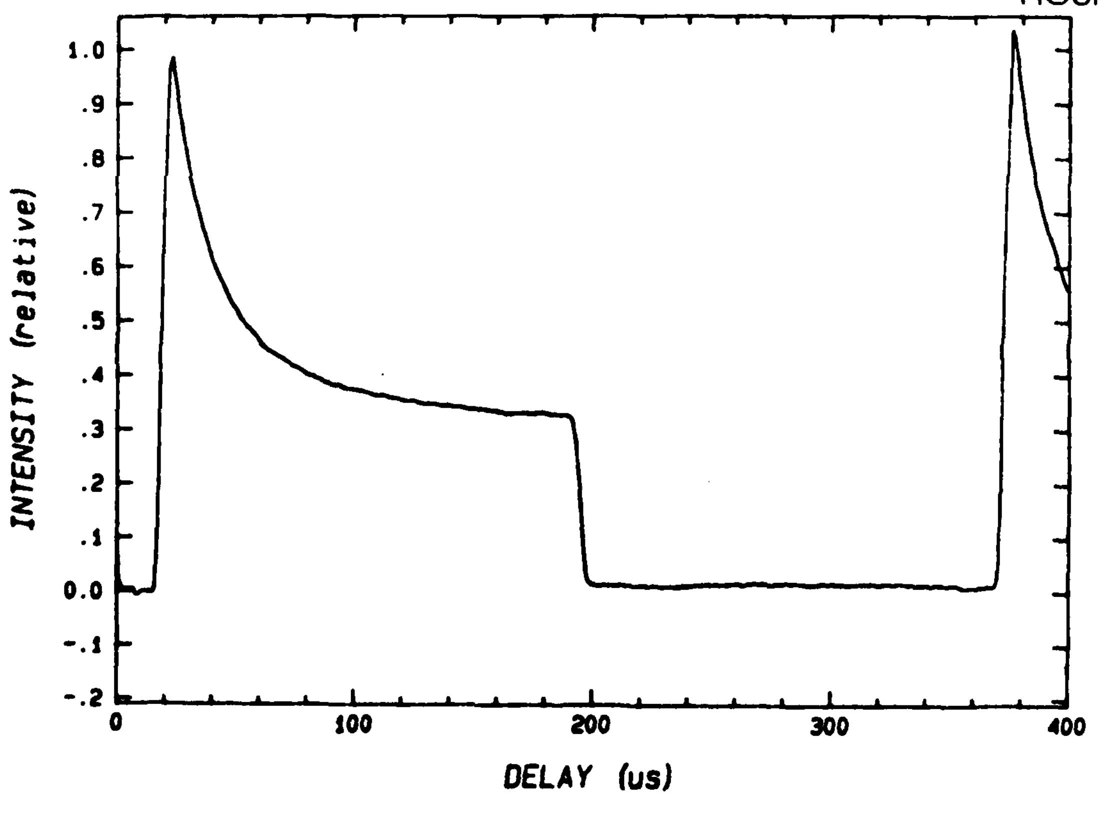


FIGURE 3

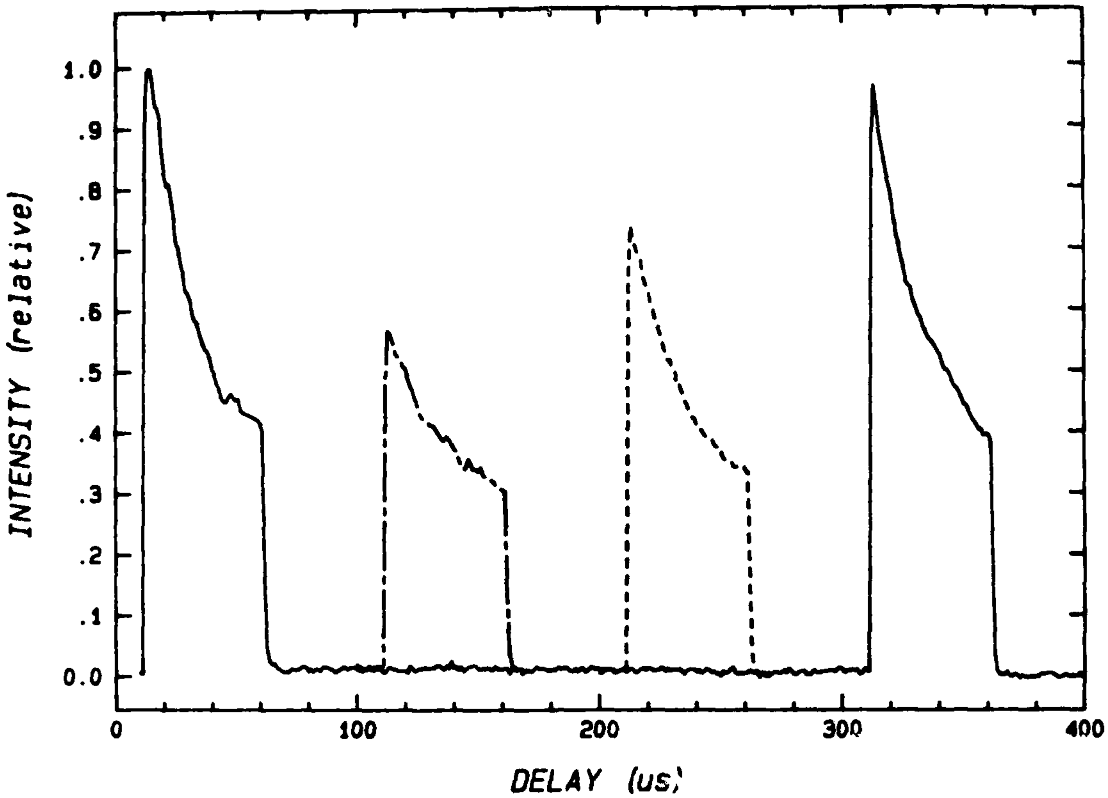
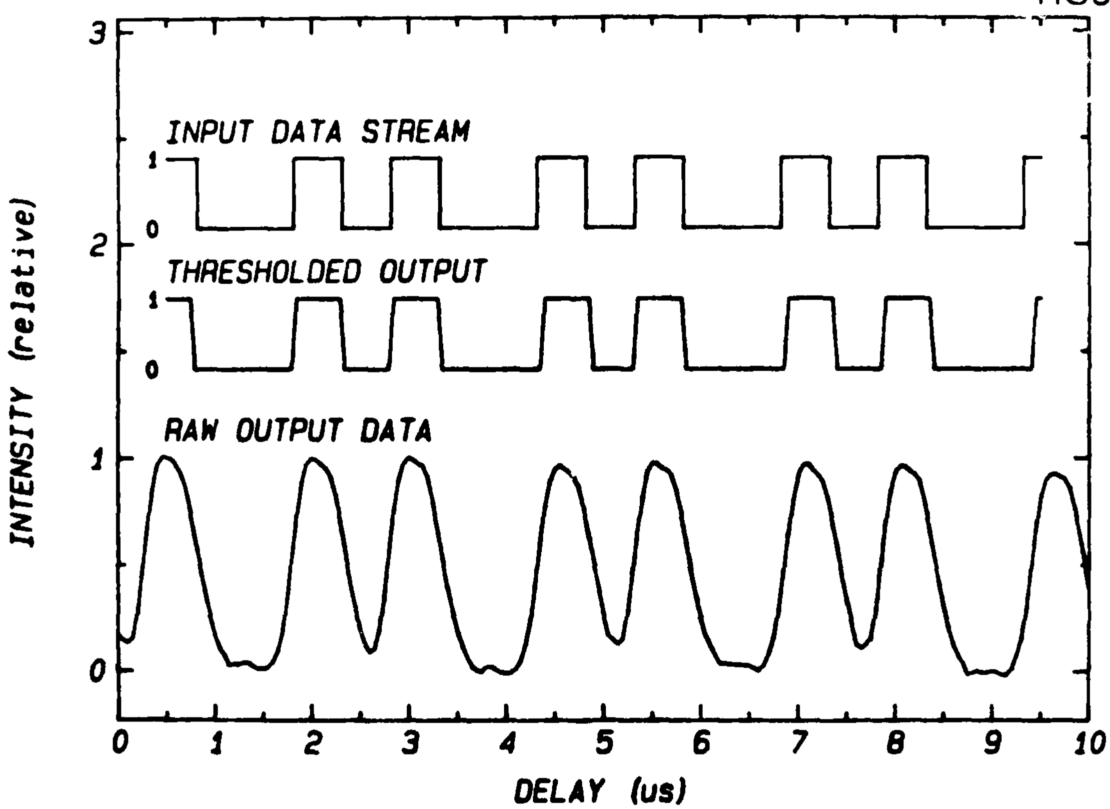


FIGURE 4



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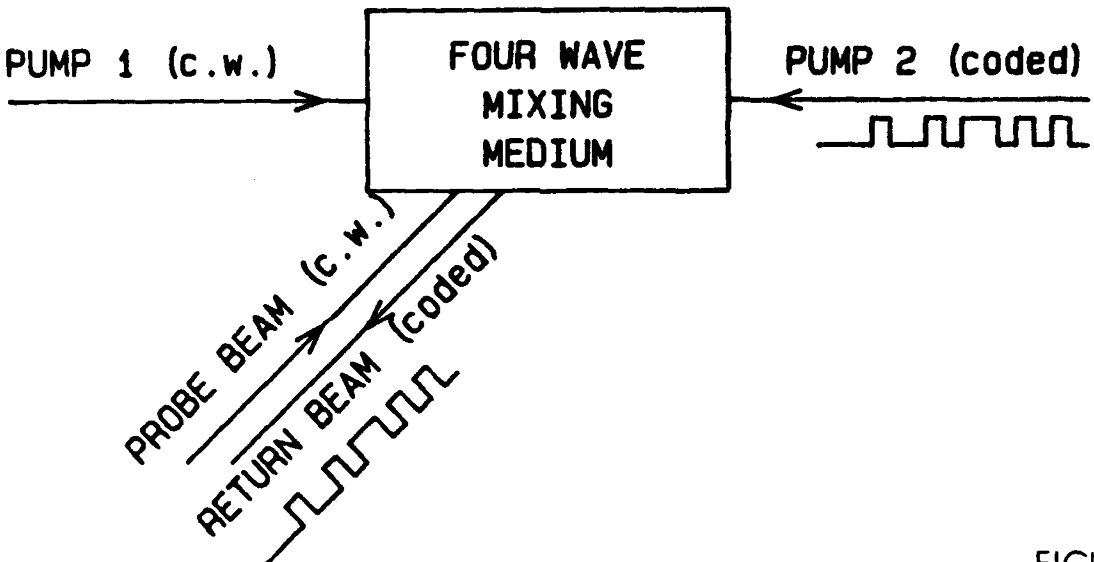

FIGURE 5

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